Aerodynamic Analysis of Male-to-Female Transgender Voice

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Summary: The attainment of a feminine-sounding voice is a highly desirable goal among male-to-female transgender (MFT) persons, but this goal may be difficult for many to accomplish. The characteristics associated with a feminine vocal quality include increases in fundamental frequency and in vocal breathiness. In this study, we used inverse-filtering of the airflow signal to indirectly assess vocal fold function in 13 MFT persons. Each participant was asked to sustain the vowel /ɑ/ first in her biological male voice and then again in her female voice. In addition, these vowel productions were compared with vowels produced by age-matched biologic women and men. The results of the study revealed a significant increase in maximum flow declination rate during female voice production. Perceptual ratings of a feminine voice were associated with a fundamental frequency (F_0) of 180 Hz or greater, although F_0 did not differ significantly between male and female voice production. These results are discussed relative to the mechanisms that obtained a feminine-sounding voice.

Key Words: Transgender voice—Perceptual analysis—Aerodynamic analysis.

INTRODUCTION

The attainment of a feminine-sounding voice is a highly desirable goal among male-to-female transgender (MFT) persons, but this goal may be difficult for many to accomplish. It is generally accepted that although administration of female hormones results in significant physical changes, the hormones do not affect the vocal folds and therefore have no significant effect on vocal fundamental frequency.[1] Rather, it seems that changes in vocal quality and pitch are transformed as a result of phonosurgical alterations and/or conscious manipulations of the laryngeal mechanism.

A variety of acoustic and perceptual analyses have been applied to the study of the MFT voice to examine those characteristics most closely associated with the female voice. The most commonly investigated measure, fundamental frequency, is the parameter most frequently manipulated by MFT persons on a conscious level. Several studies have demonstrated that MFT persons are successfully perceived as women when speaking fundamental frequency (SFF) is increased to at least 155–165 Hz.[2–4] However, a higher SFF does not seem to be the

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only parameter responsible for a feminine vocal quality. Mount and Salmon[5] reported anecdotal information concerning increased perception of a MFT person as a woman after several months of therapy that focused on raising the second formant frequency (F_2). An increase in F_2 may be obtained through a more forward position of the tongue, which results in the perception of a "thinner" voice. Finally, Andrews and Schmidt[6] noted that successful feminine perception of the MFT voice is associated with increased breathiness. This increase in breathiness may reflect an attempt on the part of the MFT person to achieve a softer, quieter voice, which is often associated with a feminine voice.

Perception of a female voice also seems to be associated with increased vocal variability relative to loudness, pitch, duration, and intonation contours.[4,6] In particular, rising contours are more marked, whereas downward contours are less extensive in range. It is thought that this reduction in phonation range for downward inflections reflects an attempt on the part of the speaker to maintain a fundamental frequency higher than typical for male speakers.

Most studies conducted on MFT persons have focused on acoustic and perceptual correlates of voice production. A more complete understanding of the speech and voice of MFT persons requires physiologic and aerodynamic data. Although the physical composition of the vocal folds may not change, the transgender speaker may manipulate the laryngeal mechanism to achieve a more feminine-sounding voice. These manipulations may result in observable changes in laryngeal control of airflow. For example, a higher SFF may result from internal laryngeal adjustments and/or increased subglottal pressure,[7] both of which could potentially affect laryngeal regulation of airflow. It is likely that MFT persons frequently attempt to achieve a higher vocal pitch through increased tension and compression of the laryngeal muscles. The additional attempt to influence vocal resonance through anterior tongue carriage to raise F2[5] may also contribute to increased laryngeal tension via contraction of the suprahyoid musculature. A possible consequence of these adjustments would be a reduction in airflow rates during MFT female voice production. In contrast, efforts to produce a breathy voice, as noted by Andrews and Schmidt,[6] may result in increased airflow rates. Clearly, the aerodynamic features of MFT female voice production may be realized in a variety of manners.

This study was conducted to assess the glottal airflow differences between the female and the male voices of transgender participants speaking in their female and male voices. In addition, the glottal airflow differences between the voices of the transgender participants and age-matched biologic female and male participants were also determined. A third goal of the study was to determine if any aerodynamic measures were correlated to listener perception of the femininity of the MFT female voice.

METHOD

Aerodynamic recordings

Participants

Thirteen MFT persons volunteered to participate in the study. The participants ranged in age from 24 to 55 years. Twelve participants completed a brief questionnaire that included questions related to general health, tobacco use, and status in the male-to-female transgender process. One participant did not complete the questionnaire.

All participants who completed the questionnaire reported that they were in good physical health and under the care of a physician. The amount of time the participants had been living as women ranged from 6 months to 18 years. Ten participants were living full time as women, and nine of these persons had undergone sexual reassignment surgery (SRS). Of the remaining four participants who had not undergone SRS, only one was living full time as a woman. In addition to hormonal supplements, ten participants were taking a variety of medications (Table 1). One participant reported that she was not taking any medications. One participant was a smoker, two others had recently quit, and nine participants were nonsmokers. Only two participants had previously received any type of voice therapy, both for a limited time.

A group of non-transgender speakers were also recruited to participate. This group consisted of 11 men and 11 women. All participants were in good

TABLE 1. *Demographic Characteristics of the Male-to-Female Transgender Participants*

Participant	Age (yrs)	Smoking	Time in transition	SRS*	Medications
TG1	52	No	3 yrs	Yes	Estradiol, Prevacid, Lipitor
TG2	28	No	3 yrs	Yes	Prevacid, Urochtine, hormone patch
TG3	44	Yes	PT†	No	Estradiol, Lithium, Proscar
TG4	55	No	9 yrs	Yes	Premarin, Prozac
TG5	55	No	4.5 yrs	Yes	Estrogen, Spirolactone, Advair, Nexium, Proventil, Proscar
TG6	30	No‡	4.5 yrs	Yes	Vasotec, Carvedriv, Prevera, Aldactone, Lanoxin, hormones
TG7	49	No	2.5 yrs	Yes	Estrogen, Progesterone
TG8	46	No‡	10 yrs (PT†)	No	None
TG9	24	NR	NR	NR	NR
TG10	53	No	6 mos	No	Serzone, Claritin-D
TG11	36	No	PT†	No	Propecia, Estradiol, Androcur
TG12	31	No	3 yrs	Yes	HIV medication
TG13	42	No	18 yrs	Yes	Hormones

*SRS, sexual reassignment surgery.

†TG3, TG8, and TG11 reported living part time (PT) as women; TG3 and TG11 did not provide information concerning length of time spent living PT as women.

‡Quit smoking 1 month before participating in study.

physical health and denied vocal tract and/or respiratory disease at the time of their participation. These speakers were included in the study only if they presented with a normal voice as judged by an experienced voice therapist and as indicated by the results of acoustic analysis of their voice during sustained vowel phonation produced at a comfortable pitch and loudness level. This analysis was completed with the *MultiDimensional Voice Program (MDVP)* (*CSL;* Kay Elemetrics Corporation, Lincoln Park, NJ).[8,9] Information concerning fundamental frequency, percent jitter, shimmer, and noise-to-harmonic ratio was obtained and compared with normative data to distinguish normal versus dysphonic voice production.[10–13]

Procedure

Each participant signed an informed consent form and completed a brief questionnaire. All participants demonstrated normal hearing levels and were free from colds or allergies on the day of testing. Voice recordings were completed in a quiet room with a circumferentially vented facemask connected to a wide-band pressure transducer. The system was calibrated with a known airflow value (0.500 L/s with a 2-L volume exchange) from a rotameter (MCU-4 calibration unit; Glottal Enterprises, Syracuse, NY) before each recording session. We used a “mask off” condition at the beginning of each recording session to recalibrate the electronic offset of the transducer from baseline to zero. Inverse-filtering of the airflow signal was completed with the *TF32* software[14] to yield a glottal airflow waveform.[15,16] All data were recorded and stored on a PCM Vetter data recorder coupled to a customized DAT recorder (Sony VDAT8; Sony Corporation, Tokyo, Japan).

Each participant was asked to prolong the vowel /ɑ/ three times at a comfortable pitch and loudness level for approximately 5 seconds. The MFT participants were asked to produce the sustained vowels first in their biological male voice and then in their female voice. Brief practice sessions were conducted before recording the voice in either condition to obtain a sample that best represented the target production. Participants were instructed to maintain a steady loudness level across all trials. Vocal intensity levels were monitored visually via an analog sound pressure level (SPL) monitor (FSPL-1; DFI Enterprises, Inc., Syracuse, NY). Trials involving excessive loudness were not included for analysis. The data were also checked after each attempt for negative minimum airflow values that would indicate possible air leakage from the facemask. Trials exhibiting such values were not included for analysis.

Measurements

The aerodynamic measurements of peak glottal airflow, minimum glottal airflow (DC flow), alternating

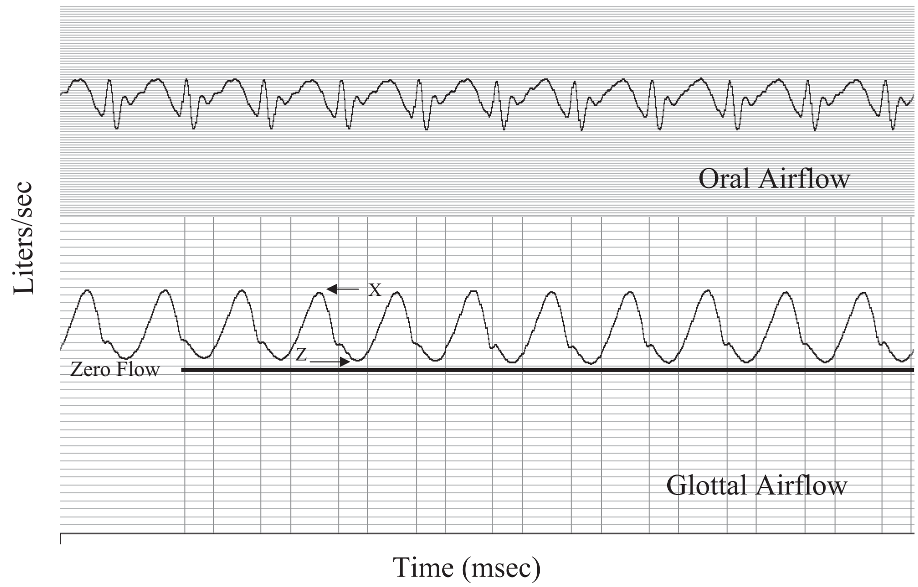

FIGURE 1. Depiction of oral airflow waveform (upper) and glottal airflow waveform (lower). Glottal airflow waveform illustrates peak airflow (point X), minimum airflow (point Z), and alternating airflow (X–Z).

glottal airflow (AC flow), and maximum flow declination rate (MFDR) were derived from the glottal airflow waveform (Figure 1). Fundamental frequency (F_0) was also derived from the airflow waveform. The relative vocal intensity was determined with the average root-mean-square (RMS) of the energy signal obtained from the vowel segment (*CSL*).

Data analysis

For each trial of sustained vowel phonation, the middle 200 milliseconds of phonation were handmarked for analysis and analyzed with *TF32*. The mid-portion of the vowel segment was used for analysis to eliminate any onset/offset effects. Means and standard deviations were calculated across the three measured vowels for each subject for each variable. Because aerodynamic parameters may be influenced by changes in vocal intensity, Pearson r correlations were computed between SPL and the aerodynamic parameters. The results of the correlation analysis revealed that no measures significantly correlated with vocal intensity. A multiple analysis of variance (ANOVA) tested the dependent variables for group differences according to gender (transgender male voice versus transgender female voice; biological male versus biological female voice). Tukey HSD comparisons subsequently examined differences among the speaker groups for the dependent variables. Because six dependent variables were included in the ANOVA, a Bonferroni correction controlled for type I errors.[17] This correction resulted in the level of statistical significance being set *a priori* at $P < 0.043$. All statistical analysis was completed with *SPSS 11.5* (SPSS Corporation, Chicago, IL).

Perceptual ratings

Fourteen undergraduate students in speech-language pathology, with little or no experience in rating voices and unaware of the purpose of the study, served as listeners. The perceptual stimuli included 36 samples of the sustained vowel /ɑ/. The first ten samples comprised five biological female and five biological male voice samples, which were randomly selected from a database of normal voice samples.[18] The remaining 26 samples comprised two repetitions of the second sustained vowel sample of the female voice productions of each MFT person. The listeners were asked to rate the masculinity/femininity of the voice sample. Ratings were made by the listeners with a visual analog scale that consisted of a 100-mm line, which ranged from a masculine voice on the left side of the scale to a feminine

TABLE 2. *Means and Standard Deviations for the Acoustic and Aerodynamic Measurements of Voice for the Male-to-Female Transgender and Biologic Male and Female Speakers*

	F_0 (Hz)	Peak flow (L/s)	DC flow (L/s)	AC flow (L/s)	MFDR (L/s/s)	SPL (dB)
Transgender man						
Mean	135.113	0.413	0.115	0.212	−346.941	66.178
SD	49.644	0.121	0.074	0.077	129.909	1.560
Transgender woman						
Mean	171.744	0.500	0.153	0.287	−486.687	66.192
SD	47.644	0.179	0.116	0.144	192.917	1.230
Biological man						
Mean	111.359	0.336	0.057	0.176	−358.827	74.349
SD	11.769	0.072	0.027	0.040	87.058	3.590
Biological woman						
Mean	191.956	0.303	0.082	0.140	−265.575	65.834
SD	21.170	0.134	0.029	0.049	79.894	6.853

voice on the right side of the scale. The listeners were instructed to mark any point along the line that corresponded with the perception of the masculinity or femininity of the voice sample. Remeasurement of 20% of the ratings revealed high intra-measurer reliability (r = 0.999) and high inter-measurer reliability (r = 0.916–1.000).

Ratings for each speaker were averaged across listeners, and a mean score of masculinity/femininity was obtained. To determine if the voice of an MFT participant was perceived as masculine or feminine, a criterion of 50% was arbitrarily assigned to the ratings of vocal quality. That is, if a speaker achieved a rating of 50 or higher on the 100-mm VAS, the speaker was determined to exhibit a relative feminine vocal quality.

Pearson r correlations were subsequently computed to determine if the perceptual ratings were associated with any aerodynamic parameters.

RESULTS

Aerodynamic recordings

Means and standard deviations of the aerodynamic and acoustic parameters for the participants are presented in Table 2. These data depict the mean and standard deviation differences that occurred between the transgender and the biologic male and female participants for all variables. As can be seen in Table 2, when the MFT speakers used their female voices, they exhibited the highest values for all four glottal airflow measures of peak flow, DC flow, AC flow, and MFDR. The biologic women produced the lowest values for the measures of peak flow, AC flow, and MFDR, whereas the biologic men exhibited the lowest values for DC flow. For F_0 and SPL, the greatest differences occurred between the biologic male and the biologic female voices.

Peak flow

As depicted in Figure 2, the peak flow values were highest for the MFT speakers during female voice production (Mean [M] = 0.500 L/s, SD = 0.179 L/s) and lowest for the biologic female speakers (M = 0.303 L/s, SD = 0.134 L/s), with the MFT male voices (M = 0.413 L/s, SD = 0.121 L/s) and biologic males (M = 0.336 L/s, SD = 0.072 L/s) exhibiting peak flow values between those of the MFT female voices and biologic female voices. The difference between the MFT female voices and the biologic females differed significantly ($F(3,48)$ = 5.752, P = 0.002, η^2 = 0.264, 1-β = 0.755). Thus, no significant differences occurred between the two MFT voicing methods or between the MFT male and the biologic male voices. The η^2 value indicates a medium effect size, which means that a good proportion of the differences between the MFT female voices and the biologic female voices in the peak values can be attributed to the group differences. The power analysis indicated that this procedure was an effective one for determining differences among the groups.

DC flow

As depicted in Figure 2, the DC flow values were highest for the MFT speakers during female

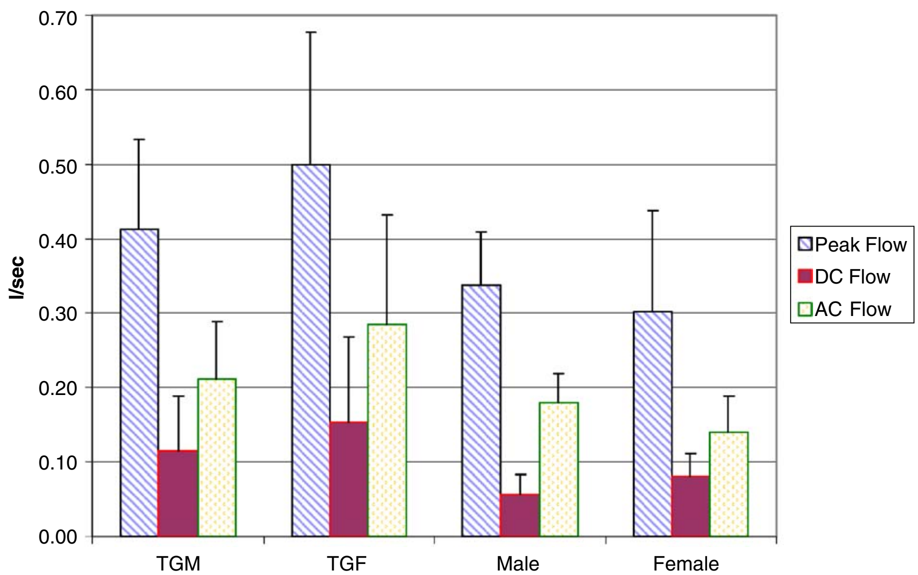

FIGURE 2. Comparison of peak glottal airflow, minimum glottal airflow, alternating glottal airflow, and maximum flow declination rates produced by the transgender speakers during male and female voice production and the biological male and female speakers.

voice production (M = 0.153 L/s, SD = 0.116 L/s) and lowest for the biologic male speakers (M = 0.057 L/s, SD = 0.027 L/s), with the MFT male voices (M = 0.115 L/s, SD = 0.074 L/s) and biologic females (M = 0.082 L/s, SD = 0.029 L/s) exhibiting DC flow values between those of the MFT female voices and biologic males. The DC flow difference between the MFT female voices and biologic males voices differed significantly ($F(3,48) = 4.350$, $P = 0.009$, $\eta^2 = 0.214$, $1\text{-}\beta = 0.581$). Thus, no significant differences occurred between the two MFT voicing methods or between the same gender MFT and biologic voices. The η^2 value indicates a medium effect size, which means that some difference in the DC values between the MFT female voices and the biologic male voices can be attributed to the group differences. The power analysis indicated that this procedure was moderately effective for determining differences among the groups.

AC flow

As depicted in Figure 2, the AC flow values were highest for the MFT speakers during female voice production (M = 0.287 L/s, SD = 0.144 L/s) and lowest for the biologic female speakers (M = 0.140 L/s, SD = 0.049 L/s), with the MFT male voices (M = 0.212 L/s, SD = 0.077 L/s) and biologic mal voices (M = 0.149 L/s, SD = 0.040 L/s) exhibiting AC flow values between those of the MFT female voices and biologic female voices. The AC flow difference between both the MFT female and male voices and both the biologic male and females voices differed significantly ($F(3,48) = 7.777$, $P < 0.001$, $\eta^2 = 0.327$, $1\text{-}\beta = 0.904$). Thus, no significant differences occurred between the two MFT voicing methods. The η^2 value indicates a small-to-medium effect size, which means that a good proportion of the difference in the AC values between the MFT voices and the biologic voices can be attributed to the group differences. The power analysis indicated that this procedure was effective for determining differences among the groups.

MFDR

As depicted in Figure 3, the MFDR values were highest for the MFT speakers during female voice production (M = 487 L/s/s, SD = 193 L/s/s) and lowest for the biologic female speakers (M = 266 L/s/s, SD = 80 L/s/s), with the biologic male voices (M = 359 L/s/s, SD = 87 L/s/s) and MFT male voices (M = 347 L/s/s, SD = 130 L/s/s) exhibiting MFDR values between those of the MFT female voices and biologic female voices. The difference between the MFT female voices and the biologic

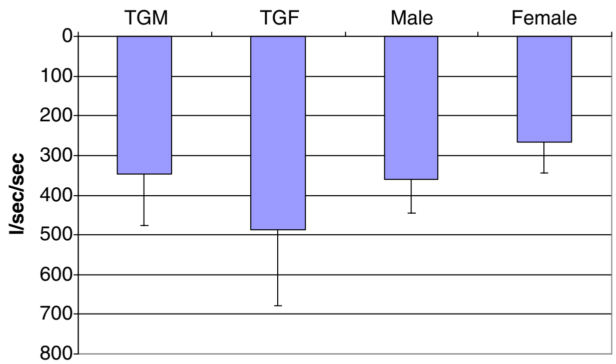

FIGURE 3. Comparison of maximum flow declination rates for the transgender speakers during male and female voice production and the biological male and female speakers.

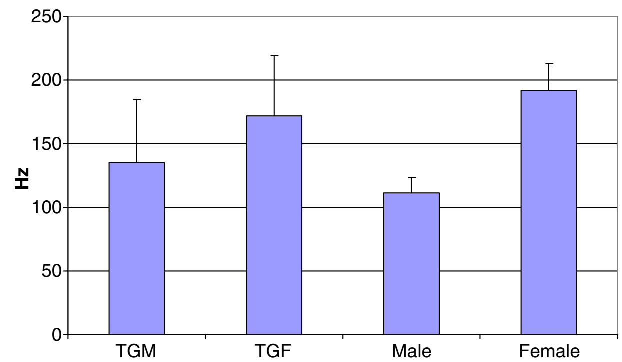

FIGURE 4. Comparison of average fundamental frequency levels during the vowel productions of the transgender speakers during male and female voice production and the biological male and female speakers.

female voices differed significantly as did the MFDR rates of the MFT female and male voices ($F(3,48) = 6.382$, $P = 0.001$, $\eta^2 = 0.285$, $1\text{-}\beta = 0.814$). The MFT male and biologic male voices did not exhibit significant differences from each other. The η^2 value indicates a medium effect size, which means that a good proportion of the differences between the MFT female voices and the biologic female voices in the MFDR values can be attributed to the group differences. The power analysis indicated that this procedure was an effective one for determining differences among the groups.

Fundamental frequency

As depicted in Figure 4, the F_0 values were highest for the biologic female speakers (M = 192 Hz, SD = 21 Hz) and lowest for the biologic male speakers (M = 111 Hz, SD = 12 Hz), with the MFT female voices (M = 172 Hz, SD = 48 Hz) and MFT male voices (M = 135 Hz, SD = 50 Hz) exhibiting F_0 values between those of the biologic female and biologic male voices. The difference between the biologic female and the biologic males differed significantly as did the F_0 levels of the MFT female voices in comparison with the biologic male voices and the MFT male voices in comparison with the biologic female voices ($F(3,48) = 12.859$, $P < 0.001$, $\eta^2 = 0.446$, $1\text{-}\beta = 0.995$). Neither the MFT male and biologic male voices nor the MFT female and biologic female voices exhibited significant differences. The η^2 value indicates a large effect size, which means that most differences between the biologic female and the biologic male voices in the F_0 values can be attributed to the group differences. The power analysis indicated that this procedure was an effective one for determining differences among the groups.

Vocal intensity

As depicted in Figure 5, the SPL values were highest for the biologic male speakers (M = 74.3 dB, SD = 3.6 dB) and lowest for the biologic female speakers (M = 65.8 dB, SD = 6.9 dB), with the MFT female voices (M = 66.2 dB, SD = 1.2 dB) and MFT male voices (M = 66.2 dB, SD = 1.6 dB) exhibiting vocal intensity values between those of the biologic male and the biologic female voices. The difference between the biologic male and all other voice groups differed significantly ($F(3,48) = 13.988$, $P < 0.001$, $\eta^2 = 0.466$, $1\text{-}\beta = 0.997$). Neither the MFT female and biologic male voices nor the MFT male and female voices exhibited significant differences. The η^2 value indicates a large effect size, which means that most differences between the biologic male and the biologic female voices in the vocal intensity values can be attributed to the group differences. The power analysis indicated that this procedure was an effective one for determining differences among the groups.

Perceptual ratings

Three listeners exhibited poor intrarater reliability, ranging from $r^2 = 0.408$ to $r^2 = 0.736$ and were

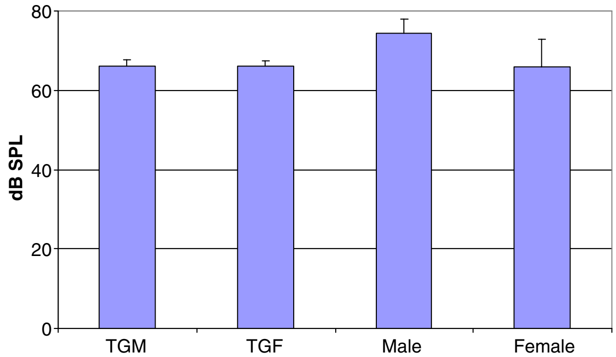

FIGURE 5. Comparison of average vocal intensity levels in relative decibels during the vowel productions of the transgender speakers during male and female voice production and the biological male and female speakers.

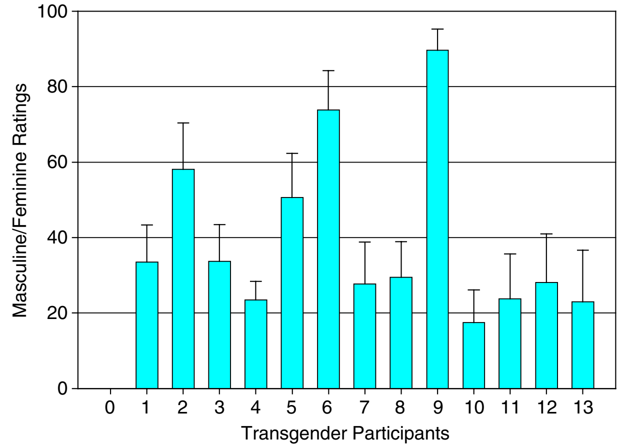

FIGURE 6. Perceptual ratings of feminine vocal quality for each transgender speaker during female voice production.

subsequently excluded from additional analysis. Intralistener reliability of the remaining 11 listeners was good, ranging from $r^2 = 0.800$ to $r^2 = 0.967$. Interlistener reliability (n = 11) was moderate to good, ranging from $r^2 = 0.714$ to $r^2 = 0.954$. As previously noted, a rating of 50 or higher on the VAS scale of masculinity-femininity was arbitrarily chosen to indicate a more feminine voice. Four MFT female voices (TG2, TG5, TG6, and TG9) were rated as feminine based on this criterion (Figure 6).

Pearson *r* correlations revealed that ratings of masculine/feminine vocal quality were strongly associated with F_0 ($r^2 = 0.981$). All four MFT speakers who obtained high feminine vocal quality ratings also exhibited F_0 values of 180 Hz or greater. No significant relationships between ratings of masculine or feminine vocal quality and the aerodynamic parameters were observed (Table 3).

DISCUSSION

MFT persons frequently attempt to obtain a more feminine vocal quality through a higher pitch and increased vocal breathiness. Several reports have documented that MFT speakers are more successful at being perceived as a woman when they exhibit a speaking fundamental frequency greater than 160 Hz.[3,4] However, Gelfer and Schofield[2] reported that a few MFT speakers with SFFs greater than 160 Hz were perceived as a man, and they suggested that an SFF of 160 Hz was not sufficient to be perceived as a woman. The results of this study agree in part with these findings. Although the MFT participants who exhibited a F_0 of 180 Hz or greater were perceived as being feminine, three speakers who exhibited F_0's ranging from 157 Hz to 174 Hz were rated as exhibiting a masculine-sounding voice. Gelfer and Schoefield suggested that additional cues, such as suprasegmental and/or contextual cues, can contribute to the perception of a female voice. Because sustained vowels were the stimuli in this study, it is likely that the higher cutoff frequency of 180 Hz to be identified as a woman was related to the absence of the suprasegmental and contextual cues found in connected speech. Prior studies examining the relationship between fundamental frequency and the perception of a female voice have involved spontaneous speech and/or reading samples, which provide additional cues to the listener.[2–4,6,19,20] Increased variability relative to loudness, rate, duration, and intonation contours during running speech also seem to enhance the perception of a feminine vocal quality.[4,6]

Although most MFT speakers exhibited increased F_0 during female production compared with their male voice, these differences did not achieve significant F_0 differences. When the MFT participants spoke in their female voices, their F_0 did not differ from the F_0 of the biologic women; and when they spoke in their male voices, their F_0 did not differ from the F_0 of the biologic men. All but one MFT

TABLE 3. *Correlations of Perceptual Ratings With Aerodynamic Measures*

Correlation	r^2	P
M/F rating—peak glottal airflow	−0.233	0.444
M/F rating—minimum glottal airflow	−0.231	0.447
M/F rating—alternating glottal airflow	−0.140	0.648
M/F rating—MFDR	−0.025	0.935
M/F rating—F_0	0.981	0.000
M/F rating—vocal intensity	0.021	0.946

participant exhibited higher F_0 for the vowels when they were using their female voices. However, the F_0 levels to which they shifted varied greatly among the participants. As shown in Table 2, the F_0 ranges for the MFT participants in both voices were wider than the F_0 ranges of either the biologic men or women. These wide F_0 ranges may have masked mean F_0 differences among the groups. Increased variability during female voice production in MFT speakers has been reported previously.[3] The ability to increase F_0 to more appropriate female levels may relate to a variety of factors, including length of time spent in transition, hormonal therapy considerations, and individual differences in laryngeal adjustments to raise F_0.

Anecdotal reports suggest that a higher pitch in these persons is achieved through excessive laryngeal tension, which often results in the perception of strained vocal quality. This perceived vocal feature is counterproductive to these persons being perceived as female speakers. In this study, the MFT persons produced significantly higher MFDR values while phonating in their female voice, which suggests a more abrupt shutoff of the glottal airflow, ie, greater closing speed of the vocal folds during phonation. Previous reports have documented an increase in MFDR with greater intensity[21,22] but not with increases in F_0.[23] Given that no significant difference in vocal intensity was observed between their male and female voices, the increase in MFDR in female voice production for the MFT speakers might seem at first to be an inconsistent finding. Possibly, however, these MFT participants closed their vocal folds quickly but not completely. This incomplete vocal fold closure would not allow the buildup of the higher subglottal pressures needed for higher vocal intensity levels.

Inspection of the data revealed that MFDR values for the MFT speakers during female voice production data exceeded the normative values previously reported for both young women, −164 to −184 L/s/s, and young men, −279 to −337 L/s/s.[22–25] These values contrast sharply to the levels reported by the MFT speakers during female voice production (Table 2).

Higher MFDR values have been reported for two populations, persons with vocal nodules and those with adductor spasmodic dysphonia.[26,27] Both types of voice disorders are associated with laryngeal hyperadduction, a vocal problem that often includes increased laryngeal muscular activity and tension.[28] High MFDR values in the MFT participants of this study may suggest increased laryngeal tension and effort while phonating. Similarly, in this study, the high MFDR values exhibited by the MFT speakers during female voice production may indicate increased laryngeal tension in an attempt to increase F_0. F_0 may be increased through contraction of the internal laryngeal muscles as well as through contraction of the supralaryngeal musculature.[29–32] Excessive stiffness and tension of the laryngeal musculature and vocal tract, such as may be observed in MFT speakers or other persons with hyperfunctional voice patterns, may contribute to greater closing speed of the vocal folds. Hence, these findings suggest that the MFT participants were attempting to achieve a more feminine sounding voice, ie, a higher pitched voice, through increased laryngeal tension.

In comparing the aerodynamic findings for the female voices of the MFT speakers with those of the biological female speakers, the MFT speakers demonstrated significantly higher airflow rates and more abrupt closure of the vocal folds. If one considers that the MFT speakers are genetically men, these findings would be consistent with available data concerning differences in aerodynamic parameters between men and women.[22,23] As discussed by previous authors, the higher airflow rates and increased speed of vocal fold closure may be attributed to the larger size of the larynx and lower rate of flow interruption during vocalization in male speakers.[22,33]

An interesting finding was that the MFT speakers exhibited significantly higher minimum flow rates

during female voice production compared with the biologic female speakers. Several studies have previously reported no significant difference in minimum flow rates between male and female speakers. A small amount of flow may be observed during the closed phase of the vibratory cycle because of incomplete closure of the cartilaginous portion of the vocal folds, vertical movements of the vocal folds, and/or variations in the stiffness of the lateral margins of the vocal tract.[22–24,34–36] Hence, it is not uncommon for both male and female speakers to exhibit small amounts of minimum flow during phonation. In this study, the higher minimum flow rates observed in the MFT speakers during female voice production is most probably related to incomplete closure of the vocal folds. Young women frequently exhibit a posterior glottal gap during phonation, a laryngeal configuration that is thought to be associated with a breathy vocal quality. To achieve a feminine-sounding voice, the MFT speakers would not only attempt to phonate at a higher F_0 but also strive for a softer, more breathy voice. The high minimum flow rate is consistent with the previously stated assumption that the MFT participants closed their vocal folds quickly but incompletely when phonating.

Another unexpected result was observed in comparing the aerodynamic parameters of the MFT speakers during male voice production with those of the biologic male speakers, as the MFT speakers demonstrated significantly higher AC flow and MFDR rates. Higher AC flow and MFDR values suggest greater vibratory amplitude and closing speed of the vocal folds, and they may be caused by a variety of factors, including increased tracheal pressures. Although data concerning tracheal pressure magnitudes were not available in this study, one may speculate that the MFT speakers used higher tracheal pressures during phonation compared with the biologic speakers. These higher pressures would be a product of increased respiratory drive as well as greater laryngeal tension associated with attempts to phonate at higher F_0 levels. These findings suggest greater movement of airflow through the vocal folds for the MFT speakers. Given that this pattern was observed in comparing the MFT male voice with the biologic male voice as well as comparison of the MFT female voice with the biologic female voice, it seems that the MFT speakers retained certain characteristics of their female voice productions when speaking in their male voice. Because most MFT speakers had spent several years living full time as women, it is possible that the MFT participants may have found it difficult to speak in their male voice. Indeed, several participants stated that they had not spoken as a male in several years and needed to "find" their male voice before being recorded. It is likely, therefore, that the adaptations used by the MFT participants to achieve a female voice had become habituated to the point that they found it difficult to phonate without inclusion of these changes. A similar process may be observed in persons with muscle tension dysphonia, who have adopted inappropriate vocal behaviors and find it difficult not to use these behaviors during the initial phase of therapy.

Certain aspects of this study may limit its generalizability to other MFT speakers. The MFT speakers included in this study represented a group of persons who differed widely in age, experiences living as a woman, length of time spent living as woman, and overall ability to portray feminine characteristics, vocal and otherwise. In addition, the treatment(s) each MFT speaker received relative to her transformation, especially in regard to hormonal therapy, differed greatly among the MFT participants. Such variability in this group of persons might not be unexpected. However, given that shifts in hormonal levels have been shown to affect vocal fold function,[37,38] the extent to which differences in hormonal medications, dosages, and duration of use by the subjects may have affected the current findings are not known. Although the current data suggest that an increase in the length of time spent living as a woman (and therefore, perhaps, an increased duration of hormonal medications) did not seem to correlate to the perception of a female voice, the possibility of hormonal influences on the transgender voice remains an area to be investigated more thoroughly. Clearly, subglottal pressure measurements would provide clearer information concerning some aerodynamic measures reported herein. Future investigations of MFT participants should include such measures. Similarly, observation of the vocal fold movement patterns via videostroboscopy would confirm if the MFT speakers

exhibit a glottal opening during female voice production. Future investigations of MFT speakers should include such measures.

CONCLUSIONS

The current findings suggest that MFT persons attempt to produce a feminine voice through increased laryngeal tension in combination with incomplete vocal fold closure. However, they accomplished this sound while using a faster vocal fold closing speed. This adjustment keeps the SPL level similar to other speakers, but it requires extra laryngeal tension. For a few transgender speakers, this laryngeal configuration seemed to be successful, as their voices were rated as relatively more feminine.

REFERENCES

1. Asscheman H, Gooren LJG. Hormone treatment in transsexuals. In: Bockting WO, Coleman E, eds. *Gender Dysphonia: Interdisciplinary Approaches in Clinical Management*. New York, NY: Haworth Press; 1992:39–54.
2. Gelfer MP, Schofield KJ. Comparison of acoustic and perceptual measures of voice in male-to-female transsexuals perceived as female versus those perceived as male. *J Voice*. 2000;14:22–33.
3. Spencer LE. Speech characteristics of male-to-female transsexuals: a perceptual and acoustic study. *Folia Phoniat*. 1988;40:31–42.
4. Wolfe V, Ratusnik DL, Smith FH, Northrop G. Intonation and fundamental frequency in male-to-female transsexuals. *J Speech Hear Dis*. 1990;55:43–50.
5. Mount KH, Salmon SJ. Changing the vocal characteristics of a postoperative transsexual patient: a longitudinal study. *J Comm Dis*. 1988;21:229–238.
6. Andrews ML, Schmidt CP. Gender presentation: perceptual and acoustical analyses of voice. *J Voice*. 1997;11:307–313.
7. Titze IR. *Principles of Voice Production*. Englewood Cliffs, NJ: Prentice-Hall; 1994:209–213.
8. Cimino AM, Sapienza CM. Consistency of voice produced by patients with adductor spasmodic dysphonia. *J Speech Lang Hear Res*. 2001;44:793–802.
9. Natour Y, Cimino-Knight A, Wingate J, Sapienza CM. The consistency of Kay Elemetrics Multidimensional Voice Program (MDVP) for the acoustic analysis of dysphonic voice. *Florida J Comm Dis*. 2002;20:23–27.
10. Hirano M, Tanaka S, Fujita M, Teresawa R. Fundamental frequency and sound pressure level of phonation in pathological states. *J Voice*. 1991;5:120–127.
11. Ludlow CL, Bassich CJ, Connor NP, Coulter DC, Lee YJ. The validity of using phonatory jitter and shimmer to detect laryngeal pathology. In: Baer T, Sasaki C, Harris K, eds. *Laryngeal Function in Phonation and Respiration*. Boston, MA: College-Hill; 1987:402–508.
12. Yumoto E, Gould WJ, Baer T. The harmonics-to-noise ratio as an index of degree of hoarseness. *J Acoust Soc Am*. 1982;71:1544–1550.
13. Yumoto E, Sasaki Y, Okamura H. Harmonics-to-noise ratio and psychophysical measurement of the degree of hoarseness. *J Speech Hear Res*. 1984;27:2–6.
14. Milenkovic P. *TF32*. Madison, WI: University of Wisconsin; 2002.
15. Rothenberg MR. Measurement of airflow in speech. *J Speech Hear Res*. 1973;20:155–176.
16. Rothenberg MR. A new-inverse filtering technique for deriving glottal air flow waveform during voicing. *J Acoust Soc Am*. 1977;53:1632–1645.
17. Keppel G. *Design and Analysis: A Researcher's Handbook*. 3rd ed. Englewood Cliffs, NJ: Prentice-Hall; 1991: 106–161.
18. Gorham-Rowan MM. *Glottal Airflow Characteristics of Adult Men and Women as a Function of Age and Intensity Level*. Unpublished PhD dissertation. Gainesville, FL: University of Florida; 2002.
19. Dacakis G. Long-term maintenance of fundamental frequency increases in male-to-female transsexuals. *J Voice*. 2000;14:549–556.
20. Van Borsel J, De Cuypere G, Van den Berghe H. Physical appearance and voice in male-to-female transsexuals. *J Voice*. 2001;15:570–575.
21. Gauffin J, Sundberg J. Spectral correlates of voice source waveform characteristics. *J Speech Hear Res*. 1989;32: 556–565.
22. Holmberg EB, Hillman RE, Perkell JS. Glottal airflow and transglottal air pressure measurements for male and female speakers in soft, normal, and loud voice. *J Acoust Soc Am*. 1988;84:511–529.
23. Holmberg EB, Hillman RE, Perkell JS. Glottal airflow and transglottal air pressure measurements for male and female speakers in low, normal, and high pitch. *J Voice*. 1989;3: 294–305.
24. Holmberg EB, Hillman RE, Perkell JS, Gress C. Individual variation in measures of voice. *Phonetica*. 1994;51:30–37.
25. Perkell JS, Hillman RE, Holmberg EB. Group differences in measures of voice production and revised values of maximum flow declination rate. *J Acoust Soc Am*. 1994;96: 695–705.
26. Hillman RE, Holmberg EB, Perkell JS, Walsh M, Vaughn C. Phonatory function associated with hyperfunctionally related vocal fold lesions. *J Voice*. 1990;4:52–63.
27. Sapienza CM, Crary MA, Gorham M. Laryngeal aerodynamic aspects of women with adductor spasmodic dysphonia. *Arch Otolaryngol Head Neck Surg*. 1995;122:383–388.
28. Colton RH, Casper JK. *Understanding Voice Problems: A Physiological Perspective for Diagnosis and Treatment*.

2nd ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 1996:79–146.

29. Erickson D, Baer T, Harris KS. The role of the strap muscles in pitch lowering. In: Bless DM, Abbs JH, eds. *Vocal Fold Physiology: Contemporary Research and Clinical Issues*. San Diego, CA: College-Hill; 1983:279–283.
30. Niimi S, Horiguchi S, Kobayashi N. F_0 raising role of the sternothyroid muscle–an electromyographic study of two tenors. In: Gauffin J, Hammarberg B, eds. *Vocal Fold Physiology–Acoustic, Perceptual, and Physiological Aspects of Voice Mechanisms*. San Diego, CA: Singular; 1991:183–188.
31. Tully A, Brancatisano A, Loring SH, Engel LA. Relationship between thyroarytenoid activity and laryngeal resistance. *J Appl Physiol*. 1990;68:1988–1996.
32. Zemlin WR. *Speech and Hearing Science: Anatomy and Physiology*. 4th ed. Needham Heights, MA: Allyn and Bacon; 1998:152–160.
33. Netsell R, Lotz WK, DuChane AS, Barlow SM. Vocal tract aerodynamics during syllable productions: normative data and theoretical implications. *J Voice*. 1991;5:1–9.
34. Hertegard S, Gauffin J. Insufficient vocal fold closure as studied by inverse-filtering. In: Gauffin J, Hammarberg B, eds. *Vocal Fold Physiology: Acoustic, Perceptual and Physiological Aspects of Voice Production*. San Diego, CA: Singular; 1991:243–250.
35. Hertegard S, Gauffin J, Karlsson I. Physiological correlates of the inverse filtered flow waveform. *J Voice*. 1992;6: 224–234.
36. Milenkovic P, Mo F. Effect of the vocal tract yielding sidewall on inverse filtering analysis of the glottal waveform. *J Voice*. 1988;2:271–278.
37. Abitbol J, Abitbol P, Abitbol B. Sex hormones and the female voice. *J Voice*. 1999;13:424–446.
38. Higgins MB, Saxman JH. Variations in vocal frequency perturbation across the menstrual cycle. *J Voice*. 1989;3: 233–243.